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RELATION OF DISPERSION TO SPECIAL CEMENTS

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FOREWORD

APPLICATION of the principle of dispersion to portland cement has received widespread recognition by the construction industry in large defense construction as well as other building. In previous papers this principle has been described in its relation to normal portland cement and the economy of its application to concrete mixes has been shown.

There are always several means of accomplishing a desired result and it is no more than reasonable to select that which is most effective and economical. In concrete to-day, the special cements offer means of securing certain specific properties desirable for particular structures and it seems appropriate to consider their relation to cement dispersion. This paper has been prepared to give the construction industry information on this subject.

Cement dispersion will accomplish many of the objectives sought in the use of special cements. Moreover, it is not incompatible with them but, on the contrary, is equally effective with the special cements as with normal portland cement in improving the properties of concrete. As a result it is found that, in many cases, the desired properties can be secured with a normal portland cement and a dispersing agent more economically than with a special cement and without some of the disadvantages which the latter may have. In other cases it is shown that the desired end can be realized most effectively and economically by application of the principle of dispersion to the special cement.

Believing that knowledge of these relations will be of value to the construction industry whenever the use of a special cement is contemplated for some specific purpose, The Master Builders Company has published this paper.

ABSTRACT

This paper reviews briefly the mechanism whereby greater efficiency of cement is attained through dispersion. The effect of this action on the properties of concrete and the relation of cement dispersion to economy are reviewed.

The various usual types of special cements and the particular properties which they enhance are described. These include:

High Early Strength cements (Type III) for high early strengths.

Corrosion Resistant cements (Type V) for resistance to sulphate corrosion.

Low Heat cements (Types II and IV) for reduction of heat evolution.

Pozzolan cements for reduction of heat evolution and corrosion resistance.

Natural cement blends for increased workability and durability.

Cements with grinding aids for increased workability and durability.

Waterproof cements for reduction in capillary attraction.

It is shown that the principle of dispersion is applicable to these special cements in the same manner that it is to normal portland cement as discussed in previous papers. It has the same effect on the special cements in reducing the water required for a given consistency and in making available a greater surface area for hydration. Consequently it has similar effects in improving durability, watertightness, volume change, strength and other properties.

There is no conflict between cement dispersion and special cements as a cement dispersing agent bears the same relation to these cements economically and with respect to the properties of the concrete as it does to normal portland cement. In some cases the desired property can be secured at lower cost and without the undesirable properties of some special cements by use of a cement dispersing agent and normal portland cement instead of a special cement. In other cases best results are attained by designing the concrete mix with a special cement and a cement dispersing agent. Whether or not it is decided to use a special cement in any particular case the highest quality of concrete can be produced at minimum cost by applying cement dispersion to the design of the concrete.

RELATION OF DISPERSION TO SPECIAL CEMENTS

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RELATION OF DISPERSION TO SPECIAL CEMENTS

INTRODUCTION

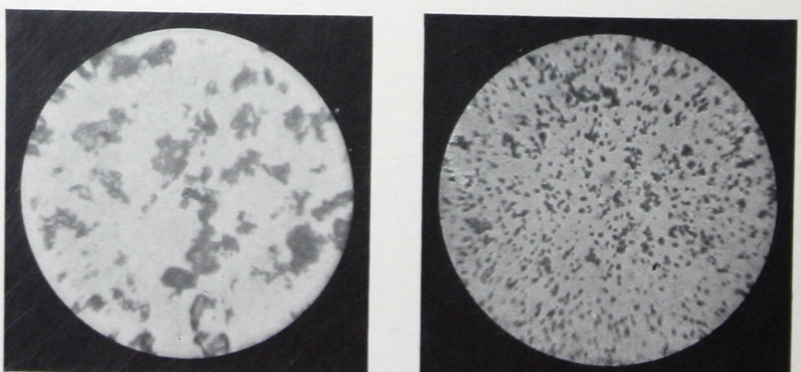
THE mechanism whereby dispersion of portland cement profoundly affects the properties of concrete has been described in a previous paper (Research Paper No. 35). In another paper (Research Paper No. 36) the economic aspects of this principle have been discussed, specifically in comparison with addition of extra cement to the mix. This material is briefly reviewed in the following three sections.

Nature of Cement Dispersion

Application of the principle of dispersion to hydraulic cements has recently assumed considerable importance in concrete construction and has found widespread use in the present defense building program. Dispersion of finely divided solid material in a liquid is not in itself new as it has been employed in ceramics, dyeing, and other fields. Dispersing agents are, however, specific in nature so that a reagent which acts to disperse some particular solid-liquid system may or may not act in a similar manner in some other system. Furthermore, an effective dispersing agent may interfere with other reactions of the system. The use of dispersion in the field of concrete and mortar has awaited the development of effective cement dispersing agents which would not interfere with the normal reactions of hydraulic cements. Such reagents were discovered about 10 years ago and since that time have been developed in the laboratory and in the field so that they are now established as a practicable means of considerable importance of improving the properties of concrete.

When portland cement is mixed with water the individual particles tend to gather together and stick to each other in clumps, i.e., the solid-liquid system is flocculated. This is due to lack of mutually

Fig. I



Cement Suspended in Water
UNDISPERSED

Cement Suspended in Water
DISPERSED

repellent electrostatic charges on the cement particles. If a suitable dispersing agent is introduced into the mix the clumps are broken up and the cement then acts as individual particles, i.e., is dispersed. (cf. Fig. I.)

Dispersion of the cement produces two important effects. The water which had been trapped within the particle clumps is released to become a part of the mixing or placing water. The surface area of the cement in contact with water is greatly increased since the particles are no longer in contact with each other. As a result of the first the amount of water required in the mix for a given consistency is less, i.e., the water-cement ratio is reduced. Since the value of the cement is dependent on a hydration reaction which is a surface phenomenon, the second effect which promotes more rapid and more complete hydration permits more efficient utilization of the cement. By the reduction in water-cement ratio and by the increase in surface area of cement available for hydration the potential value of the cement is more completely realized.

Effect of Cement Dispersion on the Properties of Concrete

Those properties of concrete which are dependent on the surface area of the cement and on water-cement ratio, and this includes most of them, must necessarily be improved by dispersion. These effects are realized in the concrete in both its plastic stage and subsequent to hardening.

During the plastic stage dispersion of the cement in a given mix will produce more placeable concrete with less water due to release of water from the cement clumps. The fattiness of the mix is increased, while segregation and bleeding are reduced, due largely to the increased effective surface area of the cement. Volume change before hardening is markedly decreased due in part to the lower water content and in part to the greater surface area.

A greater uniformity and freedom from gross defects of the hardened concrete may be expected from the improved properties in the plastic stage. Greater watertightness with reduced permeability and absorption are realized through the lower water content required for placing. Higher strengths and very greatly increased durability with respect to both freezing and thawing and sulphate corrosion may be attributed to the lower water-cement ratio of the dispersed mix and to the increased surface area available for hydration.

It is not suggested that cement dispersion is a panacea for all ills. Poor concrete will continue to exist due to poor workmanship, poor mix design, defective materials or other causes whether the cement used is or is not dispersed. What cement dispersion will do is improve the quality of good concrete or minimize the defects of poor concrete by attacking the problem along the fundamental line of using the cement more effectively.

Economics of Cement Dispersion

Granted that the application of the principle of dispersion to cement will produce definitely large improvements in the properties of the concrete the question will naturally arise whether the value of the

improvement is greater than the cost of dispersion. The economies to be effected will lie in the original cost of the materials making up the concrete mix, in the initial cost of the concrete in place as affected by workability, segregation, etc., and in the eventual cost of the structure as determined by maintenance and length of life of the structure.

The last two of these are somewhat intangible and difficult to express in specific monetary terms. There can be little question that a more placeable concrete with less tendency to segregation will reduce labor costs in placing, finishing, patching, and rubbing. Whether these savings in themselves will pay for the cost of dispersion will depend on the conditions on any particular job. Likewise it is hardly to be doubted that a more watertight durable concrete will reduce the cost of maintenance and effect a saving by extending the life of the structure. Whether the savings so effected justify the cost of dispersion will depend on the severity of the conditions to which the structure is exposed.

Material costs can be compared much more definitely and are of general applicability. A suitable basis of comparison can be found in the relation between cement dispersion and the amount of additional cement required to produce similar results. Although there will be minor variations in different localities the cost of dispersion in an average concrete mix of between five and six sacks of cement per cubic yard may be taken approximately to equal the cost of adding three-quarters of a sack of extra cement.

Data have been accumulated both in the laboratory and in the field which show that dispersion of the cement in a given mix will produce a strength equal to or greater than one additional sack of cement, will produce greater workability with respect to both mobility and cohesiveness, greater durability with respect to resistance to both freezing and thawing and sulphate corrosion, and will increase watertightness with respect to both absorption and permeability to a greater extent than will one additional sack of cement. Further, dispersion of the cement will reduce volume change and will decrease heat evolution; entirely beneficial results whereas additional cement will have the opposite effects.

In view of these results it is evident that cement dispersion is a more economical means of producing a desired effect than is the addition of extra cement. How this economic advantage will be utilized will depend on the requirements in each case. When high quality is not a factor it will be used to produce a given quality of concrete at a lower cost. Where quality is the primary consideration dispersion will produce maximum quality at a given cost.

It is generally recognized that there are many other methods of modifying one or more properties of concrete than that of additional cement and it would seem appropriate to consider the relation of dispersion to these.

The properties of concrete are influenced both by the nature of the materials from which it is made and the proportions in which they are assembled or the mix design. It is not proposed to deal with the purely physical aspects of mix proportions or characteristics of the aggregates.

It is assumed that advantage will have been taken of these factors within the limitations of available materials. It is proposed to consider here the benefits and disadvantages which are derived from some modification of the cement itself, that is, the use of special cements.

TYPES OF CEMENT

Portland cement is composed of a number of compounds, chiefly of lime, produced by burning together calcareous and silicious materials and grinding the resultant clinker to a certain degree of fineness. The more important chemical compounds of portland cement are, tricalcium silicate (C_3S), dicalcium silicate (C_2S) and tricalcium aluminate (C_3A). These constitute the bulk of the cement and more is known concerning their influence on the properties of the cement than is known concerning a considerable number of other compounds present in relatively small amounts.

It has been realized for a long time that the properties of portland cement could be materially altered by modifications in its process of manufacture. This has been given recognition by the recent adoption by the A.S.T.M. of five official classifications of portland cement. The principle factors influencing the properties of the cement are:

1. Its compound composition which in turn is influenced by the nature of the raw materials and the burning process.
2. The fineness to which the cement is ground, i.e., its surface area.
3. Additions of more or less reactive materials to the cement, usually during grinding.

The rate of cooling of cement clinker has an influence on the properties of the cement but this may be included as part of the burning process.

The five types of cement recognized by A.S.T.M. standards are as follows:

Type I. Normal portland cement
Type II. Moderate heat of hydration cement
Type III. High Early strength cement
Type IV. Low heat of hydration cement
Type V. Corrosion resistant cement

Cements falling under any of these types may be further modified by additions of less than 1% of extraneous materials, usually grinding aids, under certain conditions. There are also various other types of cements such as blended cements, masonry cements, natural cements, etc. Additions of extraneous materials other than those recognized by the A.S.T.M. have also been used. The various modified cements discussed in this paper are as follows:

1. High early strength cements
2. Corrosion resistant cements
3. Moderate or low heat of hydration cements
4. Pozzolan (blended) cements
5. Natural cements
6. Cements with grinding aids
7. Waterproof cements

It should be pointed out that the reason for the development of the special or modified cements has been the feeling that while normal portland cement has proved and still is eminently satisfactory for most purposes, in certain applications one or more properties in a higher degree than they would be present in normal portland cement would be advantageous. This has meant, usually, that in the special cement, one property has been markedly enhanced without much change in or at the expense of the others.

I. High Early Strength Cement

As its name implies, an high early strength cement is one in which strength develops rapidly. This effect may be produced in three ways, (1) by altering the compound composition, increasing C_3S and possibly C_3A, at the expense of C_2S, (2) finer grinding to produce greater surface area, and (3) the addition of an accelerator.

The advantages of high early strength are well known and need no more than passing mention. They include more rapid rate of construction, more frequent reuse of forms, reduced curing costs, and earlier utilization of the structure.

The disadvantages of high early strength cements are that usually a higher water-cement ratio is required for a given consistency and a more rapid rate of heat evolution produces greater temperature rises in concrete. The setting characteristics of the cement may also be altered so that they may affect finishing operations adversely. This last, however, does not appear to be necessarily the case.

TABLE No. I

High Early Strength cement and Normal Portland cement with Dispersing Agent (Mod.)

Concrete Mix	Cement	447 lbs.
	Sand	1346 lbs.
	Stone—¾″	1988 lbs.
	Slump	3¼ inches

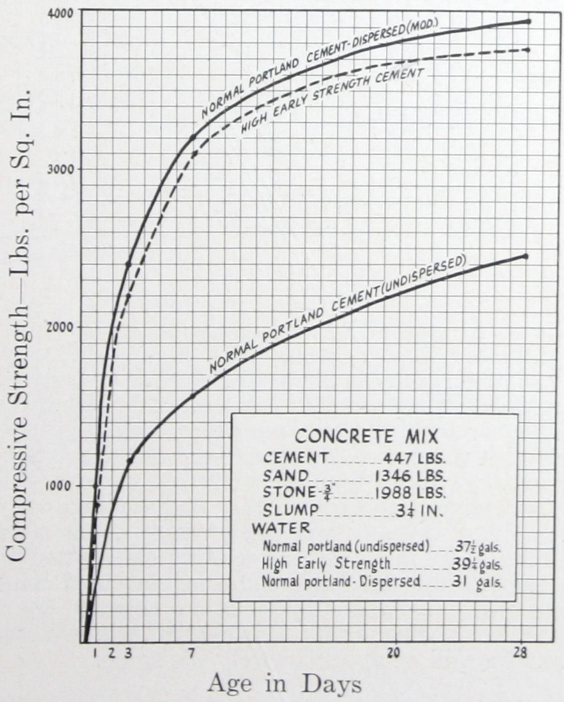
	High Early Strength Cement	Normal Portland Cement with Dispersing Agent (mod.)
Gallons water per cu. yd.	39¼	31
Compressive Strength Lbs. per sq. in.		
1 day	860	1010
2 days	1770	1730
3 days	2210	2400
7 days	3120	3210
10 days	3180	3390
28 days	3760	3950

Average for three separate series.

Whether a high early strength cement should be used in any specific case depends on the relative importance of speed and the other properties of the concrete. The properties of concrete made from high early strength cement, aside from the early development of strength, are probably not affected to any marked extent, except in the case of large masses where temperature effects are of prime importance. On the other hand they are not improved in comparison with a similar concrete made from normal portland cement and properly cured. There is some reason to believe that the slower development of strength of the normal portland cement has some beneficial effect on the ultimate properties of concrete. Where speed is a primary requisite or is of predominant importance then the use of a high early strength cement should be considered as one means of realizing this objective. It will be considered, presumably, on the basis of economy, that is, whether it is the least costly way of securing the desired strength at early ages.

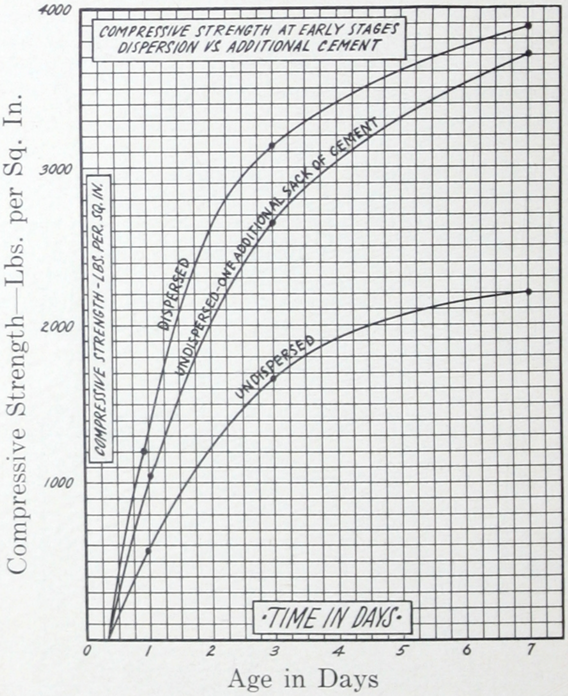
Two other methods of producing high early strengths immediately suggest themselves. These are the use of additional cement (normal portland) and dispersion. With respect to the former, sufficient additional cement will undoubtedly give strengths equal to those of high early strength cement. The use of additional cement to accomplish this purpose involves the disadvantages of higher volume change and heat evolution. Furthermore it seems hardly possible that equal strengths can be secured by the addition of an amount of portland cement equal in monetary value to the increased cost of the high early strength cement. Were this the case, high early strength cements would have no economic justification.

Fig. II



Dispersion of the cement will increase the strengths at all ages, necessarily including the early ages. This is due first to the reduction in water-cement ratio made possible by dispersion and second to the higher surface area made available for hydration. With a slight modification the use of a cement dispersing agent in the mix will give with normal portland cement early strengths equal to those of high early strength cement and higher strength at later ages (Table I and Fig. II). Likewise the dispersing agent will produce strengths at early ages higher than one additional sack of cement (Fig. III).

Fig. III



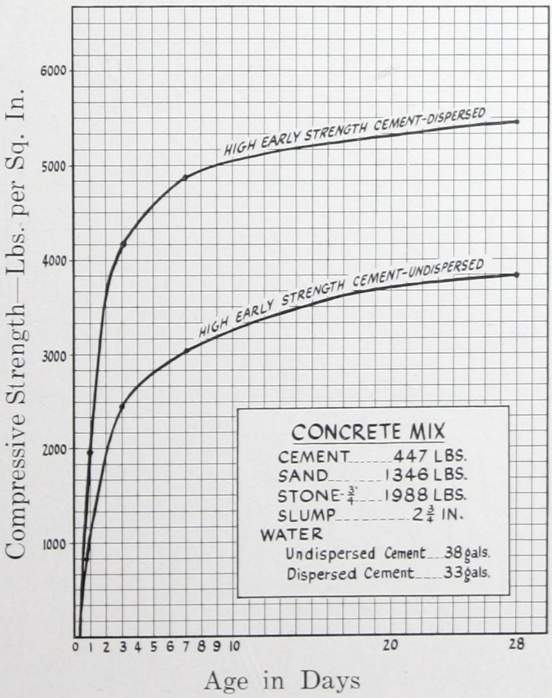
It should be noted that, although these relations between high early strengths and normal portland cements hold in a general way, there are considerable variations between different brands of cement. Thus, with an high early strength cement which gives unusually high early strengths and a normal portland which gives lower than average early strengths, the latter used with the dispersing agent may fall somewhat below the former. Conversely, with an high early strength cement of lower than average and a normal portland with higher than average early strength, the latter when dispersed may give considerably higher strengths than the former. This is to say that the relative early strengths for the high early strength cement and the dispersed portland cement in any particular case will depend on the relation between the particular brand of each which is being used, but in general, with average cements, the early strengths will be approximately the same.

The economic relations of these three methods of securing early strength can now be considered. Dispersion will cost approximately $0.40 per cu. yd. for an average concrete mix. One additional sack of cement will cost approximately $0.50 per cu. yd., and the use of a high early strength cement instead of normal portland cement about $0.70 per cu. yd. It is evident that the most economical way to secure the desired early strength is by cement dispersion.

There are certain advantages, in comparison with the use of high early strength cement, in securing the required strength by cement dispersion. Since, by this means, the increases in early strengths are secured in very large part by reduction in water-cement ratio the heat evolution will be much less. The setting characteristics of the concrete are not appreciably altered. Since dispersion permits a large reduction in water-cement ratio the well-known advantage of lower water-cement ratio such as increased durability, increased watertightness, and decreased volume change are also realized.

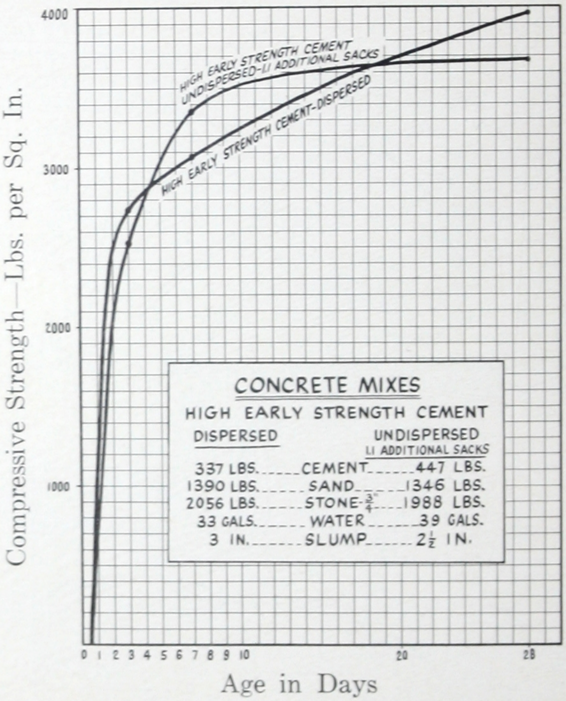
It should not be overlooked, however, that there is no incompatibility between a suitable cement dispersing agent and an high early strength cement. Actually, since the finer high early strength cements show an even greater tendency toward flocculation than the coarser normal cements, cement dispersion is even more effective. Therefore, dispersion of the high early strength cement will produce still higher early (and ultimate) strengths as well as the other advantages of lower water-cement ratio. Strength curves for an high early strength cement, dispersed and undispersed are given in Fig. IV.

Fig. IV



In this connection a comparison may be made, from an economic point of view, between dispersion and approximately one additional sack of high early strength cement. These will both give about the same strength (Fig. V). Cement dispersion, for an average concrete mix, costs about $0.40 per cu. yd. while the additional sack of high early strength cement will cost about $0.63. The conclusion is inevitable that the more economical way to secure high early strength is by cement dispersion.

Fig. V



Three methods of securing higher early strengths have been considered, use of high early strength cement, use of additional normal portland cement, and the dispersion of the cement (normal portland). Of these, the most economical is dispersion and this has the added advantage of improved properties springing from a lower water-cement ratio. When exceptionally high early strengths are required the most economical method of realizing them is by the use of a cement dispersing agent with an high early strength cement.

II. Corrosion Resistant Cements

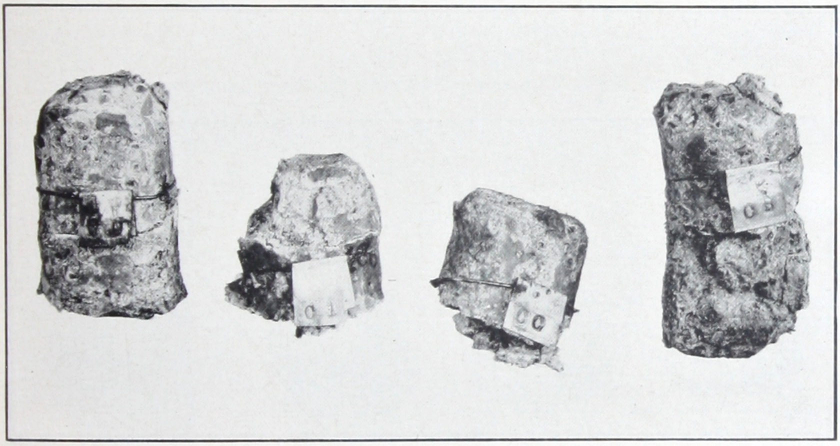
Corrosion resistant cements are designed to resist the effects of corrosion, particularly by sulphate solutions including sea water. This is accomplished primarily by the reduction of the C_3A content of the cement as this is the compound most readily attacked by sulphates. A comparison of a normal portland cement (Type I) with a corrosion resistant cement (Type V) is shown in Fig. VI.

Reduction of the C_3A content of the cement reduces the rate and amount of heat evolution which would appear to be a desirable effect.

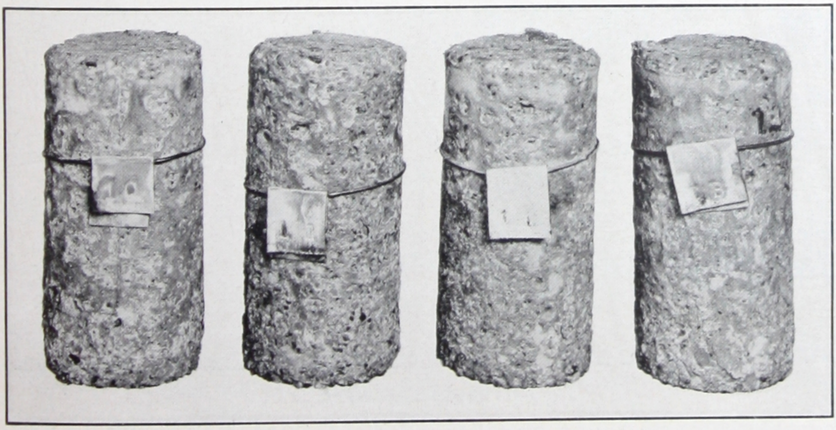
It also tends to retard setting and rate of hardening which is not undesirable except where speed of construction is a factor. Apparently the other properties of the concrete are not materially affected.

Where resistance to corrosion is important, as in structures exposed to sea water, to sulphate bearing ground waters, and to highly polluted atmospheres there would appear to be good reason for the use of corrosion resistant cements. There is no economic reason why, under such circumstances, corrosion resistant cements should not be used as these are usually obtainable at no increase in cost over normal portland cement.

Fig. VI



A. Normal portland cement
Compressive strength at 28 days — 4660 lbs./sq. in.
After 2 years in 8% Magnesium Sulphate (changed weekly)

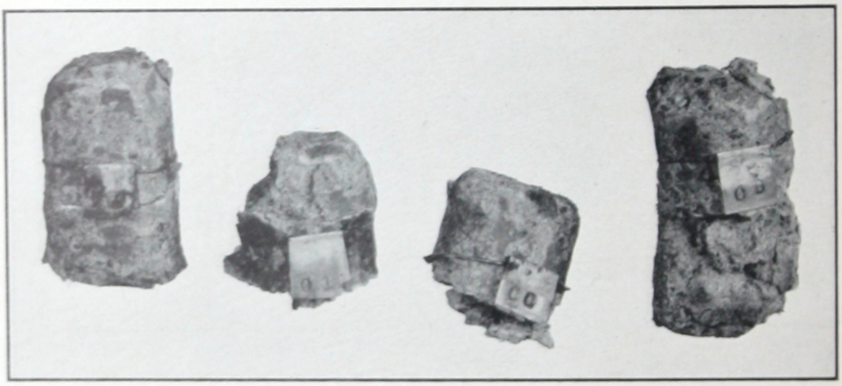


B. Corrosion Resistant cement
Compressive strength at 28 days — 5200 lbs./sq. in.
After 2½ years in 8% Magnesium Sulphate (changed weekly)

Dispersion will increase resistance to corrosion because of reduced permeability of the concrete, increased hydration under given curing conditions, and improved structure. Additional cement will also increase resistance to corrosion due to increased strength and lower permeability. The decrease in sulphate corrosion secured by dispersion is greater than that secured by addition of one extra sack of cement (Fig. VII). Since the cost of dispersion is less than one additional sack of cement the more economical way to secure corrosion resistance with normal portland cement is to design the mix with a dispersing agent. Moreover the other advantages of dispersion compared with additional cement with respect to strength, resistance to freezing and thawing, watertightness, volume change, workability and heat evolution are also secured by this means (cf. Research Paper No. 36).

Fig. VII

After 2 years in 8% Magnesium Sulphate Solution (changed weekly)



UNDISPERSED CONCRETE - 1½ SACKS ADDITIONAL CEMENT

DISPERSED CONCRETE

There may be some question whether it is possible to secure a given degree of corrosion resistance with a normal portland cement (Type I) by use of additional cement or by dispersion as economically as by the use of a corrosion resistant cement (Type V). This will depend on the

relative degrees of corrosion resistance of the two particular cements selected as there are considerable variations within each type.

Where corrosion resistance especially is sought it would seem desirable to use a corrosion resistant cement of Type V if available. Cement dispersion, however, is equally applicable to a Type V cement as it is to a Type I cement because both are naturally flocculated. The same advantages with respect to workability, strength, durability and other properties, including resistance to corrosion are secured. Data on the effect of a dispersing agent on a corrosion resistant cement are given in Table II.

TABLE No. II

	Undispersed	Dispersed
Cement	585	585
Sand	1171	1171
Stone — 3/4″	2049	2049
Water	38	33
Slump	1½	1½
Compressive Strength — Lbs. per sq. in. — 28 days	5200	6370

Here it will be seen that dispersion has similar effects with this type of cement to those which it has with a normal portland cement. Consequently, for a given degree of corrosion resistance it will be most economical to design the mix with a Type V cement and a cement dispersing agent or for a given cost the highest resistance to corrosion can be secured in this manner.

III. Low and Moderate Heat of Hydration Cements

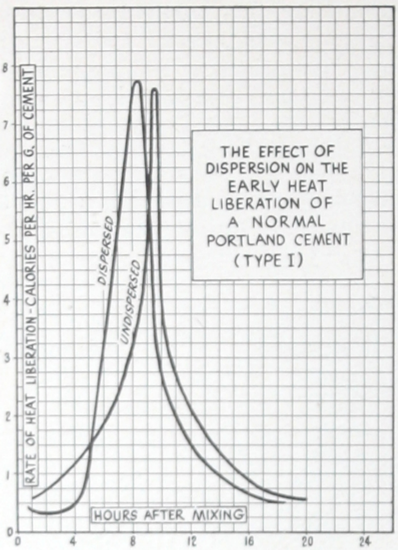
Cements with low heats of hydration were developed to circumvent the deleterious effects of rapid rate and total amount of heat evolution in raising the temperature of the concrete, particularly in mass concrete. There is some reason to believe that these heat effects are also of more importance in thinner sections than has usually been believed[1]. The reductions in heat evolution are secured by reduction of the C_3A content, or increase in the C_2S content at the expense of the C_3S, or both.

These cements have somewhat slower rates of setting and hardening than normal portland cement. Except when speed of construction is a factor this is probably beneficial rather than detrimental. Resistance to sulphate corrosion is usually improved. It does not appear that the other properties of the concrete are materially affected.

The difference between the low (Type IV) and the moderate (Type II) heat of hardening cements is one of degree rather than of kind. The low heat cement is not generally available, being supplied only in special cases for large mass concrete projects. The moderate heat of hardening cement is available in many markets and is frequently the same as or interchangeable with the corrosion resistant cements (Type V). These cements are usually supplied at no increase in cost over that of normal portland cement so that there is no economic reason why they should not be used where heat evolution is an important factor.

[1] L. A. Forbrich — J. A. C. I., Sept. 1941.

Fig. VIII



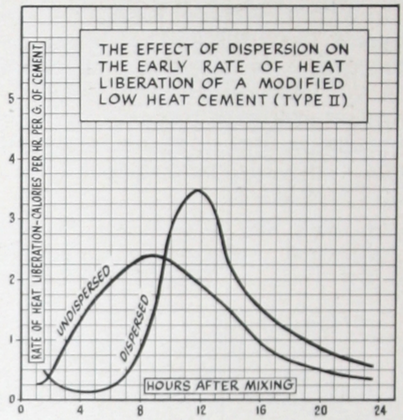


TABLE No. III

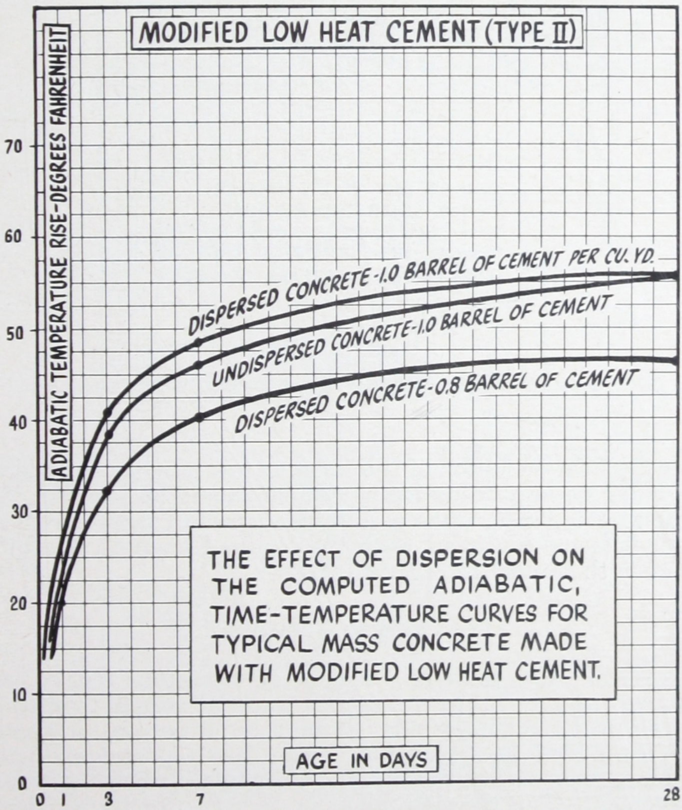
Heat of Solution

Cement	Condition	Heat Hydration— Cal. per gram 3 days	7 days	28 days
Normal (Type I)	Undispersed	70.3	85.4	103.5
	Dispersed	71.3	88.0	99.2
Normal (Type I)	Undispersed	64.8	80.7	91.3
	Dispersed	64.8	80.7	90.9
Normal (Type I)	Undispersed	65.3	77.2	92.2
	Dispersed	67.9	77.2	92.8
Normal (Type I)	Undispersed	77.5	84.8	97.1
	Dispersed	79.7	90.1	99.0
Modified (Type II)	Undispersed	53.5	64.8	77.1
	Dispersed	56.7	65.8	76.0
High Early (Type III)	Undispersed	71.7	84.4	91.8
	Dispersed	75.1	84.9	92.7
Sulphate Resisting (Type V)	Undispersed	56.7	69.2	77.3
	Dispersed	60.2	71.9	78.8

Cement dispersion produces similar effects with low or moderate heat cements as it produces with normal portland cements, with respect to workability, strength, volume change, water-tightness and durability. It, therefore, produces superior results to those which can be secured by the addition of an extra sack of cement (cf. Research Paper No. 36). Consequently the employment of cement dispersion to secure these qualities in the desired degree is more economical than the use of additional cement.

A further advantage of cement dispersion is found in the effect on heat evolution. Dispersion of a low or moderate heat cement in a given mix does not appreciably affect the rate or amount of heat evolution (Table III and Fig. VIII). Within the limits of accuracy of the determinations there are no differences in heat evolution for the dispersed and undispersed conditions of each cement. Therefore, a mix with a lower cement content and a lower rise in the temperature of the concrete (Fig. IX) can be designed using a cement dispersing agent at a lower cost, with equal or greater strength, and with equality or superiority with respect to other properties.

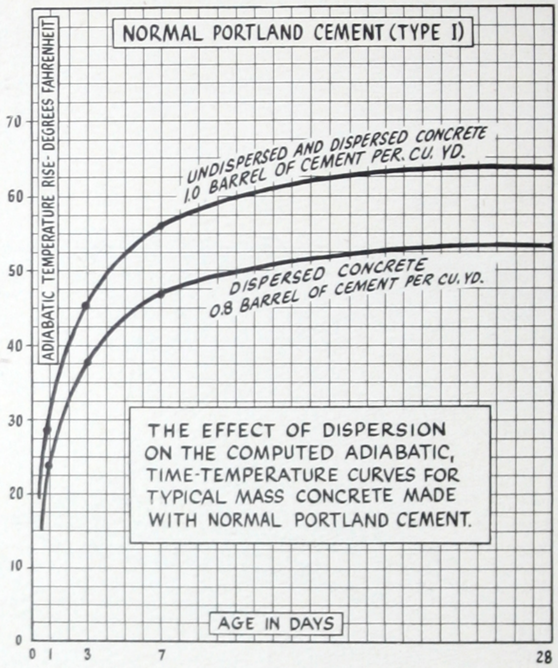
Fig. IX



The situation also may arise where low heat evolution is desired but rather higher strengths at the early ages are required than would be secured with the low heat cements (Types II and IV). In this case it is possible to take advantage of the fact that dispersion, with normal portland cement, will permit use of a minimum cement content for the required strength. Since the heat evolution is not materially affected

by dispersion this means that the temperature rise in the concrete for a given strength at the earlier ages is reduced as is illustrated in Fig. X.

Fig. X



Where the heat evolution of the concrete is a primary consideration a low or moderate heat of hardening cement should be selected. A mix should then be designed, using a suitable dispersing agent, with minimum cement factor consistent with the required strength and quality of concrete with respect to other qualities.

IV. Pozzolan Cements

A pozzolana is a material, usually of a silicious nature, which will combine with lime in the presence of water at normal temperatures to form cementitious compounds. It may be of natural or synthetic origin. When added to a portland cement mix a pozzolanic material will combine, more or less rapidly and completely, with the free lime from the cement. This reaction produces desirable results, particularly with respect to corrosion resistance, on the properties of the concrete but the extent of the improvement effected varies widely with the nature of the pozzolanic material.

From time to time special pozzolan cements have been made by grinding together portland cement clinker and a pozzolana. The quality of the resultant cement was dependent on the nature of the clinker, the nature of the pozzolana, and the proportions in which

they were inter-ground. Assuming that the nature of the materials and their proportions are such that a satisfactory pozzolan cement will be produced certain beneficial effects may be expected. These are a greater resistance to corrosion (sulphate), (Table IV), lower and slower heat evolution, and greater workability as far as cohesiveness or fattiness is concerned (Table V). The disadvantages are slower setting and slower rate of development of strength. They may also require somewhat higher water content for a given consistency than would a normal portland cement.

TABLE No. IV

Resistance to 10% sodium sulphate of 1:5:6 concrete made with fly ash (20%) cements.*

	Compressive Strength at 6 mo. lbs./sq. in.		
Fly Ash	Exposed to Sodium Sulphate	Unexposed	Ratio-Exposed to Unexposed
None	6310	5560	0.88
No. 1	6950	7120	1.03
No. 2	6800	6580	0.97
No. 3	6650	6400	0.96
No. 4	6420	5830	0.91
No. 5	5480	5060	0.93

TABLE No. V

Settlement or Bleeding of Concrete before Hardening

Cement	Condition	Depth in Inches below Original level at 24 hours
Normal Portland	Undispersed	.042
Normal Portland	Dispersed	.027
Pozzolan	Undispersed	.027
Pozzolan	Dispersed	.012

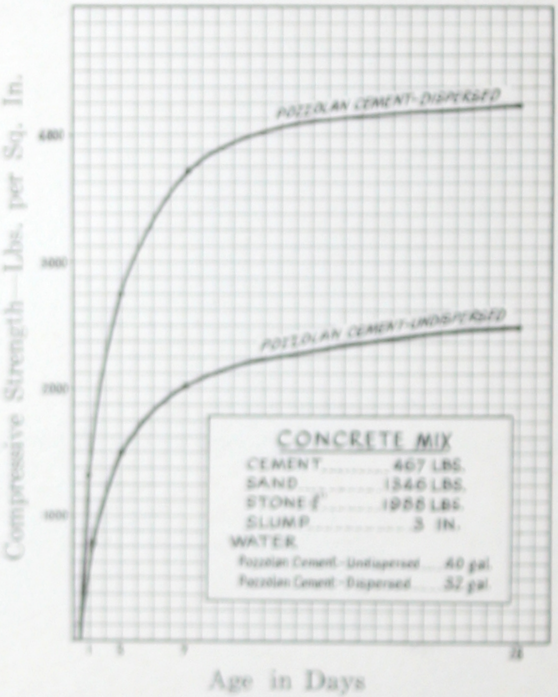
Mix —	Cement	400 g.
	Sand	450 g.
	Gravel 1/8″-3/8″	450 g.
	Slump (6″ cone)	2 in.
	Size of specimens	2″ x 4″ cylinders

In their properties pozzolan cements are very similar to low or moderate heat of hardening cements and their applicability would presumably be the same. A possible greater "fattiness" of the pozzolan cement might constitute some advantage for this type but a choice between them and the low heat types would probably be based on economic considerations. When suitable pozzolanic materials are plentifully available the pozzolan cements can probably be produced at lower cost.

*Raymond E. Davis — Properties of Cements and Concretes containing Fly Ash, June, 1938.

A cement dispersing agent will disperse both the cement and the pozzolanic material. It, therefore, produces the same relative effects on the properties of concrete made with pozzolan cement as it does on those of a normal portland, corrosion resistant, slow, or moderate heat cement (Table V, Fig. XI). The advantages of cement dispersion are therefore the same with the pozzolan cement as they are with the other types, that is, a greater improvement in the properties of the concrete for the same expenditure than would be realized by the use of extra cement.

Fig. XI



When corrosion resistance or low heat evolution, or both, are required it would seem that a pozzolan cement or cement of either Types III or IV would be selected depending on which variety of cement could be most economically manufactured in a particular locality. Then the most economical concrete mix would be one designed to produce the desired quality by the use of the cement selected with a dispersing agent.

V. Natural Cements

Natural cements were produced prior to the development of portland cement. In the early days portland cement was used as an admixture to natural cement concrete to improve the strength, especially at early ages. The natural cements, as the name implies, are

produced from a naturally occurring "cement rock" which has a composition similar to that of the portland cement raw mix. The cementitious qualities of the "rock" are developed by burning to temperatures somewhat lower than those used for production of portland cement clinker.

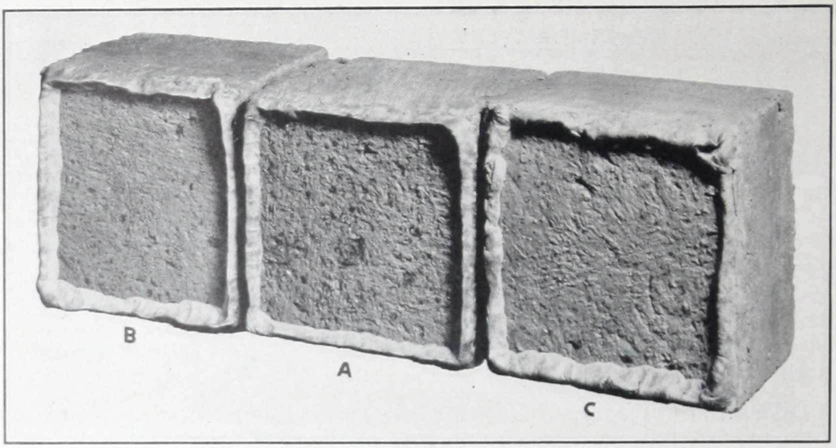
In certain respects natural cements are superior to normal portland cement although they vary widely among themselves. Because one natural cement imparts desirable properties to the concrete does not necessarily imply that some other natural cement will do likewise. The advantageous properties of natural cements are a greater degree of cohesiveness or "fattiness" which reduces bleeding and segregation, greater durability, and lower heat evolution. The chief disadvantages are slower rates of setting and hardening, lower strength, at least until after very long curing, and a higher water requirement for a given consistency.

There is no agreement on the causes for the properties of natural cements. It may be that the natural origin of the "cement rock" and the lower burning temperature produce a surface condition which favors greater water retentivity and hence fattiness. On the other hand, the properties of these cements have been attributed to the entrainment of a higher proportion of air in the mix which has been, in turn, ascribed to small amounts of oil or grease accidentally (or purposely) included in the cements during their manufacture. The observed increases in durability might be explained on the basis of reduced bleeding, which would help to prevent surface scaling, or to increased entrained air. More probably both influences are responsible. The lower heat evolution, as also the slower setting and strength development, are obviously caused by slower hydration.

Natural cements have fairly recently become popular as admixtures to portland cement. A mix made from natural cement entirely would have undesirable properties in that it would be excessively "fatty", and would have insufficient strength unless cured for a long time. Most of the recent use of natural cements has been for highway work, presumably with the objective of reducing bleeding and segregation and thereby preventing scaling of the road (Fig. XII) (A and B). Usually a 15% to 20% replacement of portland cement by natural cement has been used, that is about 1 sack in a 6 sack mix. This proportion gives a reasonable degree of fattiness and air entrainment. An excessive proportion of natural cement produces too much fattiness for good working qualities and entrains too much air so that the structural value of the concrete is impaired.

Dispersion of portland cement will produce improvements in the properties of the concrete similar to those secured with natural cement replacements. Fattiness or cohesiveness is improved and bleeding reduced. The greater fattiness of the mix will also tend towards greater air entrainment as a factor in durability. This particular property may be enhanced by a slight modification of the dispersing agent. These improvements, if secured through the dispersion of the portland cement instead of by the use of natural cements are not attended by the disadvantages of the latter. Dispersion produces higher instead of lower strengths at all ages, does not affect the rate of setting and hardening,

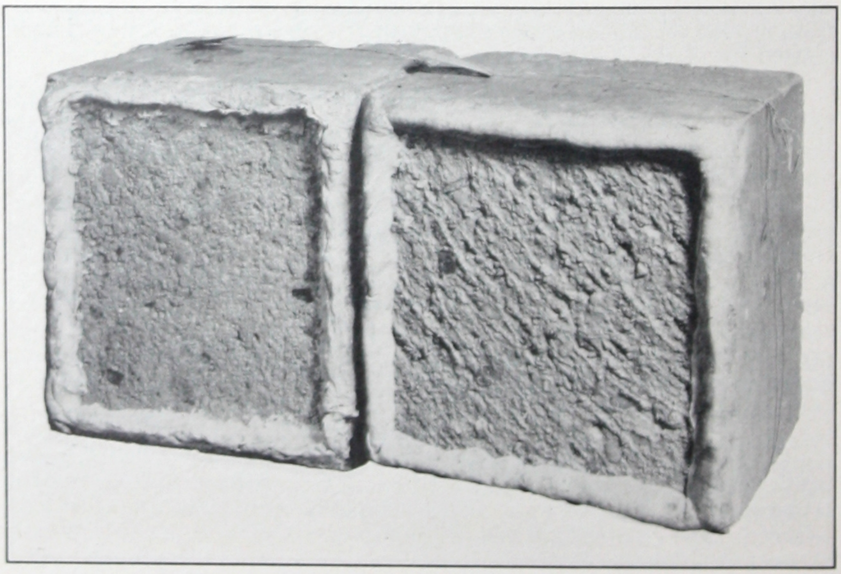
Fig. XII



Dispersed and undispersed portland cement mixes and a natural portland blend subjected to freezing and thawing cycles using calcium chloride for thawing on the top surface.

Left —B. Portland cement concrete—dispersed.
Center—A. Portland cement concrete—undispersed.
Right —C. Natural portland blend—undispersed.

Fig. XIII



Dispersed and undispersed natural portland cement blend concretes subjected to freezing and thawing cycles using calcium chloride for thawing on the top surface.

Left —Natural portland blend—dispersed.
Right—Natural portland blend—undispersed.

and permits a lower water-cement ratio instead of a higher one (cf. Research Paper No. 35).

It may, therefore, be possible to secure with normal portland cement and a dispersing agent those properties which are desirable in the portland-natural blend, fattiness and durability, without the lower strengths and slower hardening of the blend (Table VI). Whether this is the case will depend to some extent on the particular natural cement used, as these cements vary quite widely in their properties. A recent study showed that of two natural cements one was very effective in improving durability whereas the other had no effect in this respect.

An illustration of the production of similar properties to those secured with natural cement by dispersion of portland cement is shown in Fig. XII (B and C). Here are given photographs of two cement blocks made under similar conditions to those encountered in road building and finished as would be a road. Their condition after a number of cycles of freezing and thawing by the application of calcium chloride to the frozen surface shows the reduced bleeding, increased durability and resistance to scaling of the dispersed cement mix.

A cement dispersing agent for portland cement is also a dispersing agent for natural cement and will, therefore, produce the same effects with a blend as with an all portland cement mix. It is, therefore, possible to design a portland-natural blend concrete mix using a cement dispersing agent which will show greater improvement in properties than will the use of additional cement equal in monetary value to the cost of the dispersing agent. This is illustrated by the strength data given in Table VI for two concrete mixes, dispersed and undispersed, of equal cost. The added resistance to scaling so secured is illustrated in Fig. XIII and in Table VII.

TABLE VI

Portland and Portland-Natural Cements with Dispersion

	Normal Portland Cement		Blend-Portland 83½% Natural 16½%	
	Undispersed	Dispersed	Undispersed	Dispersed
Cement — lbs.	574	499	562	503
Sand — lbs.	1134	1123	1110	1132
Gravel — lbs.	2099	2070	2056	2085
Water — gals.	31.2	28.2	32.9	29.4
Slump — in.	1⅞	2¼	1⅞	1⅞
Compressive Strength Lbs. per sq. in.				
3 days	2630	2250	1970	2075
7 days	2790	2910	2310	2570
28 days	3430	3750	2760	3320

TABLE VII

Durability — Portland-Natural Cement Blend
Undispersed and Dispersed

		Undispersed	Dispersed
Natural Portland Cement	— lbs.	373	443
Natural Cement	— lbs.	94	24
Sand	— lbs.	1276	1276
Stone — ¾″	— lbs.	1992	1992
Water	— gals.	36	29¾
Slump	— in.	2	2
% loss in weight after freezing and thawing			
20 cycles		6.2	1.4
50 cycles		40.0	7.4

It should be pointed out that since dispersion and the use of natural cement both increase the fattiness of the mix, when a dispersing agent is used with a portland-natural cement blend care should be taken to design the mix to avoid excessive fattiness as this would make finishing more difficult and might cause excessive air entrainment. This may be accomplished by avoiding an excessively rich mix and an excessively large proportion of natural cement in the blend.

The desirability of using portland-natural cement blends is still a somewhat controversial subject even with respect to highway work. It has gained little acceptance in other fields. Assuming, however, that the properties of a portland-natural cement blend, specifically fattiness, are desired, and that the replacement of part of the portland cement with natural cement is contemplated, cement dispersion offers a means of securing these properties in a portland cement mix without the disadvantageous qualities of a portland-natural cement blend and at equal or less cost. If, for some reason, the use of a portland-natural blend is considered desirable, then the mix can be designed to produce the required qualities most economically with a cement dispersing agent.

VI. Cements with Grinding Aids

A number of materials have been used as grinding aids, that is, to reduce the amount of grinding of cement clinker to produce a cement of the desired fineness or surface area. Among materials which are more or less effective are vinsol resin, rosin, beef tallow, oil, grease and others. In addition to the function of these materials in facilitating grinding they also affect the properties of the cement when used in concrete with respect particularly to strength, cohesiveness or fattiness, bleeding, and the entrainment of air.

The best known grinding aid of this type and one which has been used to a certain extent is Vinsol resin. It is a by-product of the naval stores industry. When portland cement clinker is ground with a very small amount of Vinsol resin (.03% is commonly used) the grinding is greatly facilitated. What is more important, to the consumer, a cement so ground tends to entrain a considerable amount of air and to be more cohesive or fatty. In these respects the Vinsol resin ground cements produce essentially the same results as a blend of natural with portland cements.

The Vinsol cement suffers from the same disadvantage as a portland-natural blend in that strengths are lower. This decrease in strength appears to be greater for the Vinsol resin cement than for the blend and, moreover, it is permanent, that is, with long curing the strength of the concrete made with a portland-natural blend will probably equal that of a straight portland mix whereas the Vinsol resin cement will always show lower than normal strengths. Apparently the loss in strength is directly related to the amount of air entrained. Some strength data on cements ground with and without Vinsol resin are given in Table VIII. It is especially to be noted that, although the water-cement ratio is lower for the Vinsol resin cement, due to the replacement of water by entrained air, the strengths are markedly lower instead of higher as would be expected.

TABLE No. VIII

Vinsol Resin Ground Cement

Concrete Mix	— Cement	467 lbs.
	— Sand	1346 lbs.
	— Stone — ¾″	1988 lbs.

Cement	Vinsol Resin	Surface Area Sq. cm./g.	W/c gals/sk	Slump In	Compressive Strength Lbs. per sq. in. 3 days	7 days	28 days	Unit wt. Lbs./cu. ft.
A	None	2090	7.6	3	2240	3220	4450	147.5
A	.03%	2125	7.1	2¾	2350	3270	3410	143.8
B	None	1920	7.2	2¾	3025	4530	4775	148.2
B	.03%	1982	6.8	3	2230	3150	3820	139.6
C	None	1665	7.0	2½	2790	3840	4950	151.0
C	.03%	1650	6.8	3	2085	3160	3770	145.5
D	None	2100	7.5	2½	2970	3440	4760	150.0
D	.03%	2090	7.4	3	2460	3250	3860	145.5

It has been observed that the behavior of Vinsol resin cements is quite variable. The effect of a given percentage of Vinsol resin, as measured for example by the decrease in unit weight of the concrete which is an index of the amount of air entrained, seems to vary with different cement clinkers; even with clinker from the same mill produced at different times. This variation implies that the effectiveness of the Vinsol resin with respect to air entrainment, bleeding, segregation, fattiness, durability, and strength will vary. In the present state of our knowledge these variations are unpredictable. This means that, because a certain percentage of Vinsol resin is ground with the cement clinker, it does not necessarily follow that the desired properties will be secured in the same degree. A better criterion of the effectiveness of a Vinsol resin cement than the percentage used would seem to be the drop in unit weight of concrete made with the cement in question compared with a similar mix from normal portland cement. To find this weight loss, however, seems to be a matter of trial and error from one lot of cement to another.

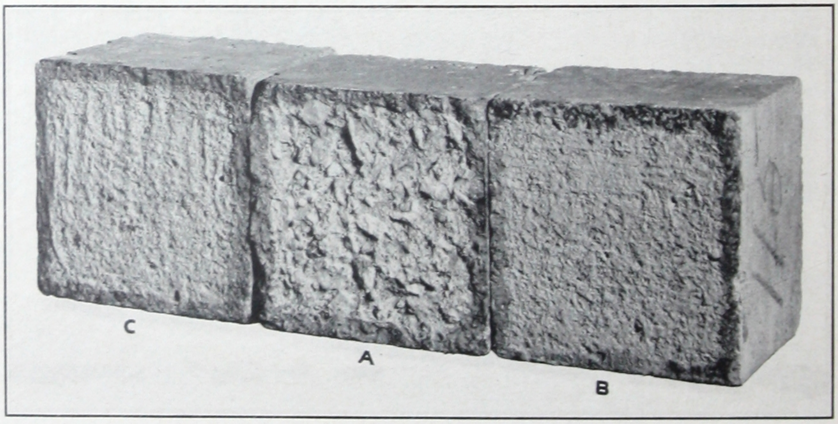
Vinsol resin cements have been offered and to some extent used as a substitute for a portland-natural cement blend, to produce similar

properties in the concrete mix, particularly increased fattiness and less tendency towards scaling. They are competitive on a cost basis as neither adds substantially to the cost of the concrete. Considering the variable performance of the Vinsol resin cement and the losses in strength which may result, it would seem that if the quality of workability which either Vinsol resin cement or the portland-natural blend will impart is desired, the choice would be on the latter.

A cement dispersing agent will disperse a Vinsol resin cement just as it will any other type of cement and consequently will have the same beneficial effect on the properties of concrete made from this variety of cement. The use of a dispersing agent with a Vinsol resin cement, however, is not recommended because the variability of these cements presents the danger that the dispersing agent with the Vinsol resin may, on occasion, produce excessive fattiness and air entrainment.

Just as in the case of natural cement blends it may be possible to produce with normal portland cement and a dispersing agent those qualities of fattiness and durability which it is intended to secure with a Vinsol resin cement (Fig. XIV). Likewise these advantages are obtained without the lower strengths of the Vinsol resin cements or their variability.

Fig. XIV



Surface area 1660 sq. cm./g.

(A) No. 108 — Compressive strength at 28 days — 3210
(B) No. 115 — " " " 28 " — 2260
(C) No. 112 — " " " 28 " — 4630

Concrete Mix

Cement	467 lbs.
Sand	1346 lbs.
Stone — $\frac{3}{4}''$	1988 lbs.
Water – A – Plain	$38\frac{1}{2}$ gals.
B – Vinsol resin	$35\frac{1}{2}$ gals.
C – Dispersed	$35\frac{1}{2}$ gals.

A comparison of a Vinsol resin cement with normal portland cement and a dispersing agent from an economic point of view is even more favorable for the latter than it would be if compared to undispersed portland cement or to portland-natural blends. If it is assumed that a Vinsol resin cement will cost approximately the same as a similar normal portland cement a rough comparison may be made. A loss in strength, if the Vinsol resin is effective, of about 20% may be expected. This is roughly equivalent to the strength imparted by one sack of cement. Assume now that a mix of 4000 lbs./sq. in. is desired and that a mix containing 5 sacks of normal portland cement will produce a strength of 3000 lbs./sq. in. Now, by the addition of a dispersing agent at a cost of approximately $0.30 per cu. yd. a strength of 4100 lbs. will be secured. By the addition of one extra sack of portland cement at a cost of $0.50 per cu. yd., a strength of 3900 lbs./sq. in. will be secured (cf. Fig. VII Research Paper No. 36 for these strength data). With the Vinsol resin cement which has lost 20% of the strength of the original mix, that is, has reduced the strength of the 5 sack mix to 2400 lbs./sq. in., in order to realize 4000 lbs./sq. in. it will be necessary to add approximately 2 sacks of extra cement at a cost of $1.00 per cu. yd. In other words, for a given strength, it will cost 20c more per cubic yard with an undispersed normal portland cement compared with the cement with a dispersing agent, and 70c more per cu. yd. with the Vinsol resin cement (Table IX). There does not appear to be any economic justification for the use of Vinsol resin cement.

TABLE IX

Type of Cement	Sacks Cement per Cu. Yd.	Compressive Strength Lbs. per Sq. In.	Cost—Dollars (Cement plus Dispersing Agent)	Additional Cost per Cu. Yd. Dollars
Normal portland cement	5.0	3000	2.50	....
Vinsol resin cement	5.0	2400	2.50	....
Normal cement dispersed	5.0	4100	2.80	....
To produce 4000 lb. concrete.				
Normal portland cement	6.0	3900	3.00	0.20
Vinsol resin cement	7.0	4000	3.50	0.70
Normal cement dispersed	5.0	4100	2.80	....

Rosin, beef tallow, oil, and similar materials are very similar to Vinsol resin. Like this last they also impair strength. On the whole such information as is available would indicate that they are less satisfactory than Vinsol resin and there is no evidence that they have received any general acceptance although some experimental highway installations have been made.

As far as the relation of these grinding aids to cement dispersion is concerned it is the same as the relation between Vinsol resin ground cements and dispersion but, if anything, less favorable to the grinding aids.

These cements can be dismissed with the statement that the same properties, if desired, can be secured with Vinsol resin or a portland-natural cement blend to better advantage. It follows that these prop-

erties can also be produced more economically and without the attendant disadvantages such as loss in strength by use of a cement dispersing agent.

Before leaving the subject of cements ground with grinding aids it should be pointed out that a cement dispersing agent may be ground with the cement clinker and one widely used grinding aid contains as a major constituent a dispersing agent. Such cements are in an entirely different category from those ground with Vinsol resin, beef tallow, rosin, etc., as strength losses are not produced and large quantities of air are not entrained but instead improvements in the properties of the concrete are secured. It would appear that there are also certain other grinding aids which facilitate grinding but do not otherwise materially affect the properties of the cement.

VIII. Waterproof Cements

A number of so-called waterproof cements have been manufactured by grinding into the portland cement clinker a small amount of some stearate or similar material. Such materials probably also function to some extent as grinding aids. The objective is to make the concrete made from these cements more or less water-repellant, that is, to destroy or reduce the capillary attraction of the voids in the concrete. A suitable proportion of stearate will successfully accomplish this purpose.

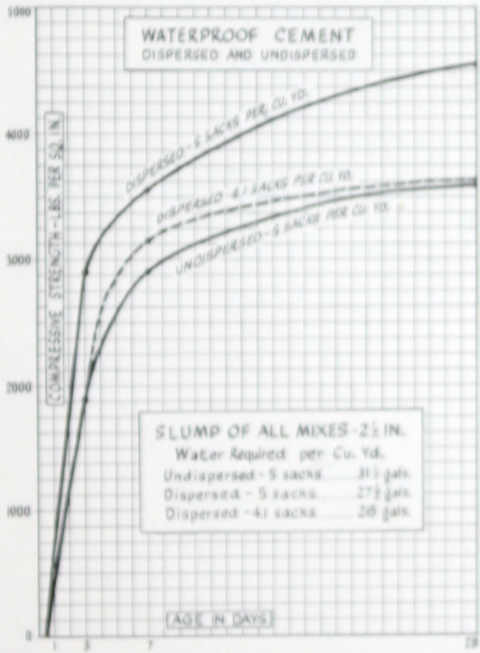
It may be questioned whether reduction of capillary attraction really makes concrete more waterproof. It is probably effective in preventing water from being drawn into the concrete in those comparatively infrequent cases where one surface of the concrete is in contact with moisture but is not under any appreciable hydrostatic pressure. There is experimental evidence to show that under hydrostatic pressure concrete containing such water-repellent materials is no less, and probably more, permeable than concrete without them. The most logical way to make concrete more nearly waterproof is to make it less permeable, that is, to reduce the volume of the interconnecting voids in the concrete. This is dependent on the reduction of the volume of excess water (water which does not combine with the cement) used per unit volume of concrete.

There is some reason to believe that the reduced capillarity of the concrete will improve durability under certain conditions. If the concrete is exposed to water, intermittently and not under pressure, there will be less tendency for the concrete to become saturated with moisture so that it should better resist freezing and thawing. Similarly concrete exposed to salt spray should be more resistant to corrosion.

A cement dispersing agent will have the same effect on a "waterproof" cement as it will have on normal portland cement with respect to decrease in water required for a given consistency and increase in available surface area of the cement. The advantages with respect to workability, strength, volume change, watertightness, and durability

which derive from these causes will be realized with "waterproof" cements (Table XV). It has been shown that the improvements in these properties will be secured to a greater extent and at lower cost by use of a cement dispersing agent than by the use of additional cement, "waterproof" or unwaterproof (cf. Research Paper No. 36). Since the waterproof cements command a premium over normal portland cements, this economic advantage will be greater with such cements.

Fig. XV



If it is desired to produce a more waterproof or less permeable concrete it would seem more effective and economical to do this by design of a mix with a normal portland cement and a cement dispersing agent. If the conditions under which the concrete must serve are such that the water-repellent qualities of a "waterproof" cement appear advantageous then a superior result may be secured at less cost by designing the mix with a "waterproof" cement and a cement dispersing agent. Whether a "waterproof" cement is more economical than a normal portland cement to which is added a stearate waterproofing paste or powder is another question which bears no relation to cement dispersion.

SUMMARY

It will be seen that there are available a number of special cements which are designed to develop some particular property of the cement to a higher degree than would be the case in a normal portland cement. This may be done either without substantial change in the other properties of the cement or at the expense of one or more of these other properties. The properties which it has been sought to improve in this manner, for particular applications, are early strength, corrosion (sulphate) resistance, heat of hydration, capillarity, and workability in the aspect of cohesiveness or fattiness. This last property has also been related to the entrainment of air and increased durability.

Cement dispersion is equally applicable to the special cements as it is to normal portland cement. It has the same effect on them in reducing the water required for a given consistency and making available a greater surface area for hydration. Consequently it has similar effects in improving durability, watertightness, volume change, strength and other properties. It is the most economical means of producing a concrete of given quality with a particular type of cement. Often it permits attainment of the desired property without the attendant disadvantages of some special cements. The relation of cement dispersion to the special cements may be looked on in three ways.

First, in many cases, the desired property in a given degree may be secured by use of a normal portland cement and a dispersing agent equally as effectively and more economically. This appears to be the case with respect to high early strengths as produced by high early strength cements. It is also true to a considerable extent with respect to workability (fattiness) and increased durability as found in pozzolan cements, portland-natural blends, and cements ground with grinding aids such as Vinsol resin. To some extent this relation also holds for increased corrosion resistance with corrosion resistant (Type V) cements, and for decreased heat evolution with modified low heat cements. In this connection it should again be emphasized that the exact relations between the properties of a special cement and a normal portland cement with dispersing agent will depend on the particular brands of each which are used as there are substantial variations in specific properties with different cements.

Second, it may not be possible to obtain some particular property of a special cement with a normal portland cement and dispersing agent. This seems to be the situation for the low heat cements (Type IV) and the waterproof (water-repellent) cements. In such cases the specific property in the desired degree may be most economically realized by designing the concrete mix with the special cement and a dispersing agent.

Third, the objective may be to endow the concrete with the property in question to the highest degree possible, that is, to a degree which the special cement alone will not attain. Here again, the most effective and economical means of so doing will be to design the concrete mix with a dispersing agent and the special cement to secure maximum durability, workability, watertightness or strength.

There is no conflict between cement dispersion and special cements as a cement dispersing agent bears the same relations to these cements economically and with respect to the properties of the concrete as it does to normal portland cement. In some cases the desired property can be secured at least cost by using a normal portland cement and a dispersing agent; in others by designing the mix with the special cement and the dispersing agent. Whether or not, in some particular case, it appears desirable to use a special cement, the maximum in quality can be realized at minimum cost by designing the mix taking advantage of cement dispersion.

Master Builders Research Laboratories
Cleveland, Ohio

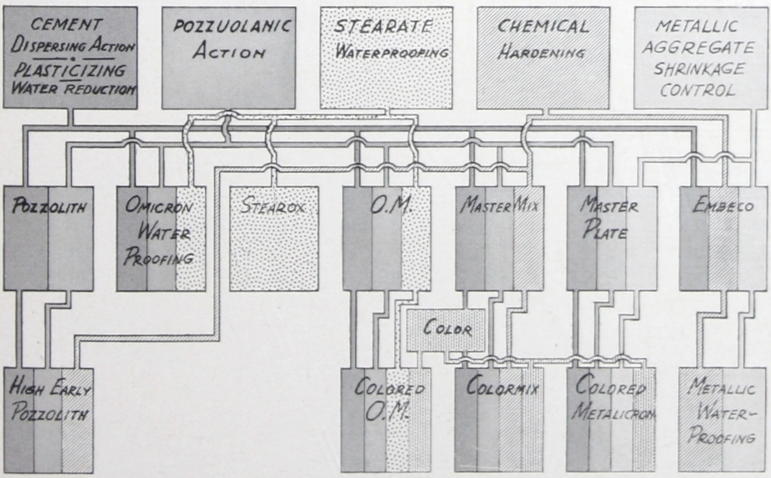
MASTER BUILDERS PRODUCTS EMPLOYING THE CEMENT DISPERSION PRINCIPLE

The principle of dispersion of cement is applicable to any type of work involving cement in mortar or concrete. This work is of a very varied nature and for different applications somewhat different properties are required. To accomplish these purposes most economically the cement dispersing agent may be combined with other basic principles for the improvement of specific properties of concrete and mortar, as illustrated by the diagram below. These include pozzolanic activity, stearate waterproofing, chemical hardening, and metallic aggregates.

The Master Builders Company has developed a group of products adapted to various specific concrete and mortar applications. The exclusive dispersing agent is incorporated in each of these products in a manner to impart the maximum effect on the resultant structure at minimum cost. These products are as follows:

Application	*Product*
Concrete (General)	Pozzolith
High Early Strength Concrete	High Early Pozzolith
Concrete (Exposed to Capillary Moisture)	Omicron Waterproofing
Floors — Heavy Duty	Masterplate
Floors — Light Duty	Mastermix
Colored Floors	Colored Metalicron and Colormix
Brick Mortar	Omicron Mortarproofing ("O. M.")
Colored Brick Mortar	Colored Omicron Mortarproofing
Grouting and Maintenance	Embeco

PRODUCT COMPOSITION DIAGRAM



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